REVIEW OF THEORY TALKS AT XXIX INTERNATIONAL SYMPOSIUM ON MULTIPARTICLE DYNAMICS

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A short summary of main results of theoretical talks presented at XXIX International Symposium on Multiparticle Dynamics is given.

1 Introduction

The main trend in theoretical applications of QCD to processes of multiparticle production during recent years, which was well presented at this Symposium, can be summarised as:
"From small to large distances or an interplay of perturbative and nonperturbative aspects of QCD".

The basis of QCD is rather well established now by a comparison of its predictions with experiments sensitive to small distances (large virtualities or momentum transfer), which can be described using the QCD perturbation theory.

On the other hand a large distance dynamics is still an open problem and we can not claim that we understand QCD without solving it. So main efforts have been concentrated on investigation of different dynamical aspects of QCD for a broad variaty of phenomena of multiparticle production. One of the crucial problems is to understand what are the relevant degrees of freedom in different processes? Are they point like quarks and gluons or "reggeized" quarks and gluons or rather white objects,- Pomeron and reggeons?

Plan of my talk is related to the problems mentioned above. In the first Section I shall concentrate mainly on small distance processes and physics of jets. In Section 2 the problem of Pomeron and its manifestations in diffractive processes and multiparticle production will be reviewed. There was a substantial progress in this field during last 2 years and in more than 50% of theoretical talks at this Symposium different aspects of this problem have been discussed. In particular in the third Section I shall consider shadowing effects in small-x physics and their relation to heavy ion interactions, though I shall not discuss the field of heavy ion interactions in details as it was perfectly reviewed by J.Stachel [1]. Other theoretical ideas and their applications to multiparticle

production processes will be discussed in Section 4.

I would like to apologize to many speakers of this Conference for being unable to cover in this talk their interesting contributions and possible misinterpretations of some results included in my summary.

2 Perturbative QCD, jets and power corrections

Large distance dynamics is present in all physical processes, even in such typical "small distance" reactions as e^+e^--annihilation at large energies or deep inelastic scattering. The factorization property in QCD allows one to separate contributions from small and large distances. For example cross section for production of jets in hadronic collisions can be expressed as a sum of convolutions of partonic distributions in colliding hadrons with corresponding hard cross sections. These cross sections can be calculated in QCD perturbation theory. A dependence of partonic distributions on a scale μ of a process can be determined using the renormalisation group equations and can be described perturbatively at large μ, while initial conditions (values of partonic distributions at fixed scale μ_0) are determined by both small and large distance dynamics and in general can not be predicted by perturbative QCD. Due to confinement of quarks and gluons in QCD they are observed as jets of hadrons and a transition from partons to hadrons is a necessary step in theoretical calculations.

Impressive agreement of perturbative QCD with experimental data has been demonstrated at this Symposium. HERA data on the proton structure function F_2 can be well described by the QCD evolution equations in a broad region of Q^2 [2] and provide an information on distributions of quarks and gluons at very small x.

Cross sections of jets production are in an agreement with PQCD calculations both at Tevatron [3,4], HERA [5] and e^+e^- annihilation [6,7,8]. Infrared safe characteristics of jets are well described by perturbative QCD if power corrections are taken into account (see below).

A substantial progress in separation of quark and gluon jets has been achieved in recent years and a trend to the asympototic prediction of QCD for multiplicities of these jets

$$\frac{\bar{n}_g}{\bar{n}_q} = \frac{C_A}{C_F} = \frac{9}{4} \tag{1}$$

is confirmed [6].

Different aspects of nonperturbative physics of jets hadronization have been discussed in several talks at this Symposium. It was shown by S.Chun [9] that the model based on area law gives a good description of relative yields

of different hadrons. An importance of spin-spin interactions, for particle production has been emphasized by P.Chliapnikov [10]. A role of nontrivial color connections between different partons, which lead to $1/N_c^2$ corrections to the leading planar configurations, has been studied by Q.-B Xie [11]. A model based on stachastic branching and local parton -hadron duality hypothesis(LPHD) was developed by A.H.Chan [12].

The LPHD hypothesis has been formulated many years ago by Azimov et al. [13] and found to be very useful for description of some global properties of multiparticle production in hard processes. An interesting new application of this LPHD was reported at this Conference by W.Ochs [14]. He calculated a probability of events in e^+e^--annihilation with a rapidity gap. For partons such events with absence of partons in a large region of Δy are suppressed by Sudakov factor. If LPHD is correct suppression of the same type should exist also for hadrons.

It is clear that LPHD can not be true in all situations and it is very important to understand why it works and where it fails? First experimental indications to violations of LPHD has been discussed in several talks at this Symposium [6,17,15].

Hadronisation effects in properties of jets are closely related to power corrections to these quantities, which were found to be essential for accurate description of jets observables. This problem clearly reflects an interplay between PQCD and large distance physics. There is a hope that these corrections can be described in terms of a quantity $\alpha_0(\mu)$, which is an average value of the strong coupling $\alpha_s(k^2)$ in the region of small virtualities $k^2 < \mu^2$ [16]. Such approach is useful only if $\alpha_0(\mu)$ is universal for different observables. These corrections were found to be approximately universal for jets observed at LEP [8] and at HERA [17], though HERA experiments indicate to some differences between values of $\alpha_0(\mu)$ from different observables. In my opinion an agreement is better than one can expect for such a simple model of power corrections.

Perturbative approach to production of events with large rapidity gaps between jets in hadronic collisions has been discussed by G.Sterman [18]. He proposed to characterize a hadronic activity in rapidity region between jets by energy flow Q_c and have shown that it is possible to describe by perturbative QCD the region where Q_c is much smaller than p_T of jets but larger than characteristic hadronic scale.

Cross sections of semihard interactions in hadronic collisions fastly increase with energy and multiparton interactions become important at superhigh energies. This problem has been addressed in several talks [19,20,21,22,23].

Properties of multiparton distributions have been discussed by D.Treleani and G.Calucci [19,20]. These distributions are characterized by ratios of momenta

x_i and impact parameters b_i of all partons. It was pointed out that simplest uncorrelated distribution fails to reproduce experimental data on cross section of double parton interaction and possible correlations between valence quarks and gluons can lead to an agreement with experiment.

Applications of models with multiple partonic interactions to total interactions cross sections in h-h,$\gamma - h$ and $\gamma - \gamma$ collisions have been considered by G.Pancheri [21] and to multiparticle production by R.Ugoccioni [22]. W.D.Walker [23] has demonstrated that multiple interactions are needed for understanding of Tevatron data on multiplicity distributions.

Impressive collection of new results on interactions of real and virtual photons has been presented by LEP experiments [24,25]. A fast increase with energy of these cross sections is observed at highest energies. It is difficult to reconcile the increase observed by L3 group for $\gamma - \gamma$ interactions with theoretical models based on an eikonalized version of mini-jet model [21]. First results on interaction of highly virtual photons provide a good testing ground for recent predictions based on NLO BFKL Pomeron calculations [26].

Spin effects in processes of interaction of a virtual photon with proton have been discussed by N.Nikolaev [27]. He have shown that simplest diagrams of two gluon exchange for vector meson production by highly virtual photons leads to the spin structure of $\gamma^* V$ transition, which is in an agreement with HERA data (see also [28]). In particulat the model leads to a definite pattern of violation of s-channel helicity conservation. It was also shown in this talk that due to double-Pomeron exchange structure function g_2 has a singular behaviour as $x \to 0$. As a result the Burkhardt-Cottingham sum rule and Wandzura-Wilczek relations are violated.

3 Pomeron

The notion of the Pomeron has been introduced in particle physics in the framework of Regge theory long ago [29]. There is a revival of interest to the Pomeron problem due to small-x physics studied at HERA. The Pomeron plays an important role in theoretical descriptions of high-energy interactions, however there are no unique definition of this object. So I shall first discuss existing definition of the Pomeron. They can be devided into two categories:
a) Pomeron is the Regge pole with the largest intercept $\alpha_P(0)$ and vacuum quantum numbers. It gives a contribution to high-energy amplitudes of elastic scattering and other diffractive processes. In this approach multipomeron exchanges, which lead to moving cuts in the complex angular momentum plane j, exist also. They are especially important in the case of "supercritical" Pomeron (when $\alpha_P(0) > 1$) to restore unitarity of the theory and to satisfy Froissart

limit.
b) Pomeron is the singularity at $j = 1$ (not a Regge pole in general), which satisfies constraints of unitaruty, analyticity and describes asymptotically diffractive processes.

I prefer the first definition due to the following reasons:
i) It relates high-energy scattering to hadronic spectrum.
ii)It is natural in $1/N$-expansion in QCD.
iii) Multiparticle content of the Pomeron is known (short range correlations).
iv) Gribov reggeon diagrams technique allows one to estimate amplitudes for multipomeron exchanges and AGK (Abramovsky, Gribov, Kancheli) cutting rules relate them to multiparticle production processes. Such approach leads to a successful phenomenology [30].

It is very important to understand dynamics of reggeons and of the Pomeron in QCD. A useful framework to classify all diagrams in QCD is 1/N-expansion [31], where N is either number of colors N_c or light flavors N_f. In this approach the reggeons ρ, ω, A_2, are connected to planar diagrams, while the Pomeron is related to cylinder type diagrams. Diagrams with exchange by n Pomerons in the t-channel are connected to multicylinder configurations, which are $\sim (1/N^2)^n$ and are small in the large N limit. In realistic calculations these contributions should be taken into account. Such classification leads to many predictions for high-energy hadronic interactions, which are in a good agreement with experiment [30].

Calculation of reggeon and Pomeron trajectories in QCD with an account of nonperturbative effects is a difficult problem (for some recent results see below). Perturbative calculations of the Pomeron in QCD have been carried out by L.Lipatov and collaborators [32] (BFKL Pomeron) many years ago. Pomeron is related to a sum of ladder type diagrams with exchange by reggeized gluons. Reggeization of gluons (as well as quarks) is an important property of QCD (at least in perturbation theory). In the leading approximation an expression for the intercept of the Pomeron is well known [32]

$$\Delta \equiv \alpha_P(0) - 1 = \frac{4N_c ln2}{\pi}\alpha_s \tag{2}$$

In this approximation it is not clear which value of α_s to use and for $\alpha_s = 0.2$ an intercept of the Pomeron is substantially above unity $\Delta \approx 0.5$. It leads to a fast increase of total cross sections $\sim (s/s_0)^{\Delta}$ with energy. The arguments were given that next to leading corrections to the Pomeron intercept should be large [33,34]. This is connected to the observation of relatively small average rapidity intervals in the gluon ladder for realistic values of α_s, while LO expressions are valid for large rapidity intervals. NLO corrections have been calculated last

year[35,36] and strongly modify LO results for Δ

$$\Delta = 2.77\alpha_s(1 - 6.5\alpha_s) \tag{3}$$

For $\alpha_s > 0.15$ Δ becomes negative. It is clear that an origin of large NLO corrections should be clearly established and resummation of these effects is necessary.

Some results in this direction were presented at this Conference. It was pointed out by V.Kim[26,37] that results for Δ depend on a choice of renormalization scheme and renormalization scale (original result was obtained in $\bar{M}S$-scheme). The choice of more physical (BLM) scheme leads to more stable results for Δ, which practically does not depend on Q^2 and $\Delta \approx 0.17$.

Another approach has been developed by M.Ciafaloni et al. [38] and was presented by D.Colferai[39]. They perform a partial resummation of subleading corrections using renormalization group analysis. In the case of two scales processes (like DIS) an intercept of the "hard Pomeron" $\alpha_P(Q^2)$ is introduced and investigated. This quantity can determine behaviour of structure function F_2 for large Q^2 and not too small x. It is pointed out that an intercept of the leading Regge pole α_P (which is of course should not depend on Q^2) depends on dynamics in nonperturbative region. The Pomeron problem is a clear manifestation of an interplay of soft and hard mechanisms in QCD.

An importance of nonperturbative effects and especially of chiral symmetry breaking effects for dynamics of the Pomeron was emphasized by A.White[40]. He uses a powerful tool of reggeon unitarity for investigation of interactions of reggeized gluons and quarks in QCD. An important role of the special U(1) anomaly was demonstrated.

New factorization formula for high-energy scattering amplitudes was obtained by Ya.Balitsky[41]. It allows one to formulate an effective action, which can be used for calculation of higher order perturbative corrections to BFKL Pomeron and unitarization effects. This approach is effective for small coupling α_s and large fields. Related approach has been developed by L.McLerran with collaborators[42] and was reported at this Conference in talks of J.Jalilian-Marian[43] and R.Venugopalan[44].

It is very important to understand a role of multigluon exchanges for asymptotic behaviour of scattering amplitudes. This problem has been studied in the eikonal approximation by H.Fried[45].

Interesting attempt to calculate spectrum of glueballs using metods developed in the superstring theory has been presented by R.Brower[47]. The leading Regge trajectories of the glueball spectra can be related to the Pomeron Regge pole. Recently Yu.Simonov and myself have calculated spectrum of glueballs using method of vacuum correletors[46]. Predicted masses of the lowest glue-

balls are in a perfect agreement with lattice calculations. We emphasize an importance of mixing between gluons and quarks in the low t-region. The mixing effects allow to obtain phenomenologically acceptable intercept of the Pomeron trajectory and lead to an interesting pattern of vacuum trajectories in the positive t-region. I think that the Pomeron in QCD has a very rich and interesting dynamics.

4 Shadowing effects in small-x region and "hard" diffraction

Experiments at HERA clearly demonstrated a fast increase of densities of quarks and gluons as x decreases. For very large densities partons will interact and shadow each other. This will lead to a suppresion of the fast rise of parton densities and finally to saturation of parton densities as $x \to 0$.

Same effects can be viewed in the target rest frame as a result of coherent multiple interactions of the initial quark-gluon fluctutation of a virtual photon with the target (note that a fluctuation of a virtual photon with small x has a very long lifetime $\tau \sim 1/mx$). In the framework of the reggeon theory these rescatterings correspond to multipomeron exchanges in $\gamma^* p(\gamma^* A)$ elastic scattering amplitudes. Investigations of a role of multipomeron exchanges for dense parton systems have been discussed by E.Gotsman [48] and B.Gay Ducati [49]. An equation, which includes all multipomeron exchanges in the double logarithmic approximation has been obtained [49] from the dipole picture. It coincides with AGL equation obtained ealier using Glauber-Mueller approach and can be considered as a candidate for unitarized evolution equation at small x. Effects of the rescatterings (or screening corrections) on the structure function $F_2(x, Q^2)$ have been considered in details by E.Gotsman and the problem of saturation for parton densities was discussed.

Rescatterings in reggeon theory are closely related to diffractive production (large rapidity gaps). Experimental results of HERA on these processes have been discussed at this Symposium by A.Zhokin [2] and K.Piotrzkowski [50] There was a considerable interest in the processes of "hard" diffraction in recent years. If the Pomeron is a factorizable object than one can introduce the Pomeron structure function, which characterize a distribution of quarks in the Pomeron $F_P(\beta, Q^2)$. Experiments at HERA found that effective intercept of the exchanged object for large rapidity gap events $\Delta_{eff} = 0.15 \div 0.2$ at large Q^2. This value is larger than corresponding values in soft diffraction. Structure function of the Pomeron was also determined by H1 and ZEUS [2].

The model for distribution of quarks and gluons in the Pomeron has been considered by F.Hautmann [51]. It is based on perturbative QCD approach to this problem with the assumption of dominant role of small transverse sizes

for initial distribution of quarks and gluons in the Pomeron. Dependence on Q^2 was calculated using standard QCD evolution.

Note that for inelastic diffraction multipomeron exchanges are also present (and even more important than for elastic amplitudes) and in general amplitudes of these processes are not factorizable. A simultaneous sefconsistent description of both $F_2(x, Q^2)$ in a broad region of Q^2 and diffractive production $F_2^{D3}(x, Q^2, \beta, x_P)$ is a difficult problem. First results in this direction were presented at this Symposium [52].

The problem of "saturation" at large Q^2 and x much smaller than those available at HERA is still not solved completely. The region of $ln(1/x)$ and Q^2, where the saturation happens should be well defined and the question whether $\sigma_{\gamma^* p}$ is large($\sim Const$) or it is still small ($\sim 1/Q^2$) should be solved.

Results on hard diffraction at Tevatron have also been presented at this Conference [53,54]. Diffractive production of jets, W-bosons, b-quarks and J/ψ-mesons is observed at $\sim 1\%$ level. These signals are $5 \div 10$ smaller than expected from Regge factorization. This damping factor is expected due to large shadowing effects for inelastic diffraction in hadronic collisions. A similar suppression takes place for total cross section of diffraction dissociation. Theoretical estimates show that these shadowing effects due to multipomeron exchanges influence mostly total rate and s-dependence of diffractive processes, but have a little effect on mass or β-dependence. From this point of view an observation of very fast increase in diffractive production of jets at very small β observed by CDF group [53] looks very interesting. It contradicts to the parametrisation of distribution for gluons in the Pomeron proposed by H1. Same comparison should be done for other parametrisations of gluons proposed in literature. Note that direct information on small beta behaviour of partonic distributions in the Pomeron (especially for gluons) is practically absent at HERA.

An important testing ground for Regge factorization and its vilolation is provided by the process of central production of jets, heavy quarks, e.t.c in hadronic interactions with two large rapidity gaps (double Pomeron exchange). Experimental information on this process is still very limited and more data are clearly needed.

Experimental information on diffraction production, including hard diffraction, can be understood using the prescription of "flux renormalisation", introduced by K.Goulianos [55]. At present it does not have clear theoretical basis and it is necessary to understand why it works in many situations.

Another explanation of "Dino's paradox" has been proposed by Chung-I Tan [56]. He emphasizes a role of "flavouring" of the Pomeron, which accounts for preasymptotic effects due to delayed thresholds of heavy states production. In this approach it is possible to describe a slow rise of σ^{SD} at very high

energies. It would be interesting to see how this approach reproduces main observational facts for hard diffractive processes.

Shadowing for dense parton systems in the small x region are especially important for nuclei, where density of partons for given impact parameter is larger by a factor $A^{1/3}$. Nuclei are also convenient for a study of these effects as they can be easily extracted by a study of A-dependence of nuclear structure functions. This problem has been discussed in several talks [44,43,52,57]. Though the models considered in these talks are rather different their predictions look similar. In particular for heavy nuclei ($A \approx 200$), $Q^2 \sim 5GeV^2$ and $x \sim 10^{-4}$ there is a suppression factor $0.5 \div 0.6$ due to shadowing.

This result is important also for heavy ion collisions at RHIC and LHC as it reduces density of produced minijets (and hadrons).

Same effects were considered in the model of string fusion in the talk of M.Braun [58]. He discussed a possible phase transition due to percolation of strings and its influence on fluctuations in heavy ion collisions.

5 Models for multiparticle production and phenomenological applications

In this section I shall consider some new developements in models of multiparticle production and applications of existing theoretical ideas to different aspects of high-energy interactions.

The model of color mutations with self-similar dynamics for particle production in soft processes has been discussed by R.Hwa [59]. A general organisation of diagrams is similar to the one used in $1/N$-expansion approach,- the Pomeron corresponds to the cylinder contribution and multipomeron exchanges in the eikonal approximation are also taken into account in this model. Dynamics of multiparticle production for a single cylinder differs from string models. It is especially important for local (in rapidity) properties of particle production. The model reproduces experimental data on intermittency, which pose a problem for existing string models.

Applications of existing models based on $1/N$-expansion, reggeon theory and string dynamics to cosmic ray physics have been presented by R.Engel [60]. Comparison of predictions of these models with existing cosmic ray data indicate to possible problems of existing models at superhigh energies.

The Pomeron in perturbative QCD is related to exchange by even number of gluons in the t-channel. Exchanges by odd number of gluons lead to a singularity in j-plane with negative signature and C-parity, which is usually called "odderon". Recent perturbative calculations established that in LO approximation intercept of the odderon is below unity, but very close to it.

Experimental observation of manifestations of odderon would be an important check of perturbative QCD predictions (note that lattice calculations indicate that nonperturbative glueball trajectories of this type have a very low or even negative intercept). It was shown in the talk of C.Merino [61] that an asymmetry in distribution of charm jets produced in diffractive photoproduction is sensitive to odderon contribution.

Interesting applications of small-x QCD physics to superhigh energy $\nu N(\nu A)$ interactions and attenuation of ν transversing the Earth have been discussed by A.Stasto [62]. Such calculations are important for ν-astronomy as well as for investigation of atmospheric neutrinos.

I think that this Symposium demonstrated that our field of QCD studies in processes of multiparticle production is very rich and active. Most topical problems now are related to connection between soft and hard dynamics in QCD. There are many interesting relations between different fields like small-x DIS and heavy ion collisions. New experiments at RHIC and later at LHC will give a new impact to this field of research.

I would like to thank organizers of this Symposium and especially Chung-I Tan for invitation to participate and to give theoretical review talk at the Symposium.

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